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RESULTS OF THE QUALIFICATION TEST OF EIGHT JPL-SR-28-3 ROCKET MOTORS AT SIMULATED ALTITUDE

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ARO, Inc.

November 1966

ROCKET TEST FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The test program reported herein was requested by the National Aeronautics and Space Administration (NASA), for the Jet Propulsion Laboratory (JPL), under System 920E, Project 0393.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The test was conducted in Propulsion Engine Test Cell (T-3) of the Rocket Test Facility (RTF) from July 20 to August 23, 1966, under ARO Project Number RC1611, and the manuscript was submitted for publication on October 10, 1966.

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This technical report has been reviewed and is approved.

John W. Hitchcock
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ABSTRACT

Eight Jet Propulsion Laboratory JPL-SR-28-3 solid-propellant rocket motors were test fired under the combined effects of rotational spin at 100 rpm, temperature conditioning at 100°F (4 motors) and 40°F (4 motors), and an average pressure altitude in excess of 100,000 ft, as the Qualification Test Phase of the Applications Technology Satellite Apogee Motor Program. The primary objective of the program was to determine motor performance during simulated flight conditions. Secondary objectives were to measure motor case and nozzle temperatures for 300 sec after ignition and to evaluate the motor case and nozzle structural integrity. Motor performance is presented and compared with data from earlier AEDC test firings of the same type of motor.

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NOMENCLATURE

A_e Nozzle exit area, in.^{2}

A_t Nozzle throat area, in.^{2}

C_f Average thrust coefficient, based on primary burn time

$\overline{C}_f$ Average thrust coefficient, based on 1 sec of data taken 1 sec before t_{bd} and post-fire throat area

I_{sp} Specific impulse based on the manufacturer's stated propellant weight and primary burn time, lb_f-sec/lb_m

I_{vac} Vacuum impulse, based on primary burn time, lb_f-sec,

$$\int_{t_o}^{t_{bd}} F dt + A_{e_{avg}} \cdot \int_{t_o}^{t_{bd}} P_{cell} dt + \overline{C}_f \cdot A_{t_{post\text{-}fire}} \cdot \int_{t_o}^{t_p} P_{ch} dt$$

M_x Arithmetic mean of values for each group

n	Number of samples
P_{cell}	Test cell pressure, psia
P_{ch}	Motor chamber pressure, psia
t_a	Action time, time interval between 10 percent of maximum chamber pressure during ignition and 10 percent of maximum chamber pressure during tailoff, sec
t_{bd}	Nozzle flow breakdown time, time (from time of increase in chamber pressure during ignition) at which exhaust nozzle flow breakdown occurs during tailoff, as indicated by an increase in test cell pressure caused by exhaust gas diffuser flow breakdown, sec
t_ℓ	Ignition lag time, time interval from the time at which firing voltage is applied to the igniter circuit to the time of increase in chamber pressure, sec
t_o	Zero time, time at which firing voltage is applied to the igniter circuit, sec
t_p	Primary burn time, time interval from time of increase in chamber pressure during ignition until the time of minimum chamber pressure at tailoff prior to residual burning, sec
t_s	Time nozzle throat flow becomes subsonic, time (from time of increase in chamber pressure during ignition) until the time at which the ratio of chamber pressure to cell pressure has decreased to 1.3 during tailoff, sec
W	Manufacturer's stated propellant weight, lb_m
X_i	Value of sample for each firing
σ	Standard deviation,

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - M_x)^2}$$

SECTION I
INTRODUCTION

The Jet Propulsion Laboratory JPL-SR-28-3 solid-propellant rocket motor is scheduled for use in the Applications Technology Satellite (ATS) (Fig. 1 and Ref. 1). The ATS is planned as a general purpose satellite capable of operation in a synchronous earth orbit with experimental instruments in the areas of meteorology, communication, radiation, navigation, gravity gradient stabilization, and various other engineering experiments. The JPL-SR-28-3 rocket motor will provide the final velocity increment required at the apogee of the elliptical transfer orbit to place the satellite into a synchronous orbit (Ref. 1).

As part of the apogee motor preliminary and development test phases, four motors were successfully fired at pressure altitudes during earlier tests at the AEDC. Two of these motors were fired in a nonspin mode. The remaining two motors (Ref. 2) were fired while spinning about the motor axial centerline at 100 rpm.

The eight motor tests reported herein were conducted as part of the qualification test phase of the JPL-SR-28-3 rocket motor program. The primary objective was to determine motor performance under the combined effects of rotational spin (at 100 rpm) and pressure altitude. Secondary objectives were to measure motor case and nozzle temperature for 300 sec after ignition and to evaluate the motor case and nozzle structural integrity.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The JPL-SR-28-3 solid-propellant rocket motor (Fig. 2) is a full-scale, flightweight motor with the following nominal characteristics:

Length, in.	54
Diameter, in.	28
Loaded Weight, lb_m	860
Propellant Weight, lb_m	760
Thrust, lb_f	6000
Chamber Pressure, psia	250
Burn Time, sec	43
Throat Area, in.^{2}	13.1

Motor weight and physical dimension data are presented in Table I.

The cylindrical motor case, which is insulated with a nitrite-butadiene rubber liner bonded to both the propellant and motor case, is constructed of 6 AL-4V titanium alloy. An aluminum thrust attachment ring is brazed to the forward hemispherical surface of the motor to transmit the motor thrust to the spacecraft. A large head-end fixture (not flight hardware) was bolted to the thrust attachment ring to assist in motor handling. The handling fixture remained attached to the motor at all times during ground handling and testing.

The nozzle assembly contains a high-density graphite throat insert that extends into the diverging portion of the nozzle to an area ratio of approximately 1.15:1. The diverging portion of the nozzle from an area ratio of approximately 1.15:1 to 7.2:1 is fabricated of carbon cloth phenolic, and from an area ratio of 7.2:1 to the exit plane, it is fabricated of silica cloth phenolic. The contoured nozzle has a nominal area ratio of 35:1 and a 9.8-deg half-angle at the nozzle exit. The nozzle contained a throat closure to prevent foreign matter and moisture from entering the motor.

The motor utilizes a composite-type solid propellant designated JPL-540 (ICC Class B), which is ignited by a basket-type igniter (Fig. 3) loaded with ALCLO® (aluminum-potassium perchlorate) pyrotechnic pellets and slugs. Each of the two single bridgewire squib initiators (Hi Shear® PC 37) used an electrical energy source of 4.5 amp for ignition

The motor igniters incorporated a safe-and-arm (S & A) device (Fig. 3). This unit, both mechanically and electrically, blocks the squibs from the igniter's primary charge when in the "safe" position.

2.2 INSTALLATION

The motors were cantilever mounted from the aft bearing of a spin fixture assembly in Propulsion Engine Test Cell (T-3) (Ref. 3). The spin assembly was mounted on a thrust cradle, which was supported from the cradle support stand by three vertical and two horizontal double-flexure columns (Fig. 4). The spin fixture assembly consisted of a 10-hp squirrel-cage-type drive motor, a forward thrust bearing assembly, a drive shaft and thrust pylon, and an aft bearing assembly. The spin fixture rotates counterclockwise, looking upstream. Electrical leads to and from the igniter, pressure transducers, and thermocouples on the rotating motor were provided through a 52-channel slip-ring assembly mounted on the drive shaft. Axial thrust was transmitted through the drive shaft-thrust bearing assembly to two load cells mounted just forward of the thrust bearing.

Pre-ignition pressure altitude was maintained in the test cell by a steam ejector operating in series with the RTF exhaust gas compressors. During a motor firing, the motor exhaust gases were used as the driving gas for the 35.25-in.-diam, ejector-diffuser system to maintain test cell pressure at an acceptable level.

2.3 INSTRUMENTATION

Instrumentation was provided to measure axial thrust, test cell pressure, motor chamber pressure, igniter pressure, motor case and nozzle temperatures, and motor rotational speed. Table II presents instrumentation ranges, recording methods, and system accuracies for all measured parameters.

The axial thrust measuring system consisted of two double-bridge, strain-gage-type load cells mounted in the axial double-flexure column forward of the thrust bearing on the rocket motor centerline.

Unbonded strain-gage-type transducers were used to measure test cell pressure and low-range (0- to 15-psia) chamber pressure. Bonded strain-gage-type transducers in ranges from 0 to 300 psia and 0 to 3000 psig were used to measure motor chamber and igniter pressure, respectively. Chromel®-Alumel® (CA) thermocouples were bonded to the motor case and nozzle (Fig. 5) to measure outer surface temperatures during and after the motor burn time. Rotational speed of the motor and spin rig assembly was determined from the output of a magnetic pickup.

The output signal of each measuring device was recorded on independent instrumentation channels. Primary data were obtained from four axial thrust channels, three test cell pressure channels, one igniter pressure channel, and three motor chamber pressure channels. These data were recorded as follows: Each instrument output signal was indicated in totalized digital form on a visual readout of a millivolt-to-frequency converter. A magnetic tape system, recording in frequency form, stored the signal from the converter for reduction at a later time by an electronic digital computer. The computer provided a tabulation of average absolute values for each 0.10-sec time increment and total integrals over the cumulative time increments.

The output signal from the magnetic rotational speed pickup was recorded in the following manner. A frequency-to-analog converter was triggered by the pulse output from the magnetic pickup and in turn supplied a square wave of constant amplitude to the electronic counter, magnetic tape, and oscillograph recorders. The scan sequency of the electronic

counter was adjusted so that it displayed directly the motor spin rate in revolutions per minute.

The millivolt outputs of the thermocouples were recorded on magnetic tape from an analog-to-digital converter at a sampling rate for each thermocouple of 50 samples/sec.

A photographically recording, galvanometer-type oscillograph provided an independent backup of all operating instrumentation channels except the nozzle and motor case temperatures. Selected channels of thrust, pressures, and temperatures were recorded on null-balance, potentiometer-type strip charts for analysis immediately after a motor firing. Visual observation of the firing was provided by a closed-circuit television monitor. High-speed, motion-picture cameras provided a permanent visual record of the firings.

2.4 CALIBRATION

The thrust calibration weights, thrust load cells, and pressure transducers were laboratory-calibrated prior to usage in this test. After installation of the measuring devices in the test cell, all systems were again calibrated at sea-level nonspin ambient conditions and at simulated altitude while spinning at 100 rpm.

The pressure systems were calibrated by an electrical, four-step calibration, using resistances in the transducer circuits to simulate pressure levels. Thermocouple systems were calibrated by using known millivolt levels to simulate thermocouple outputs. The axial thrust instrumentation systems were calibrated by applying to the thrust cradle known forces, which were produced by deadweights acting through a bell crank. The calibrator is hydraulically actuated and remotely operated from the control room.

After each motor firing, with the test cell still at simulated altitude pressure, the systems were recalibrated to determine any shift.

SECTION III
PROCEDURE

Eight JPL-SR-28-3 solid-propellant rocket motors arrived at AEDC on June 21, 1966. The motors were visually inspected for possible shipping damage and radiographically inspected for grain cracks, voids, or separation and found to meet criteria provided by the manufacturer.

During storage in an area temperature conditioned at 75 ± 5°F, the motors were checked to ensure correct fit of mating hardware, and the electrical resistance of the igniters was measured. The nozzle throat and exit diameters were obtained, the igniter and S & A mechanism assembly was installed and the entire motor assembly was weighed and photographed. Before installation in the test cell, four motors were temperature-conditioned at 40 ± 2°F, and four motors were conditioned at 100 ± 2°F for a minimum of 72 hr.

After installation of a motor in the test cell which has a temperature control capability, the motor centerline was axially aligned with the spin axis (within 0.004 in.) by rotating the motor and measuring the deflection of flange surfaces A5 and B5 (Fig. 5) with a dial indicator. Test cell temperatures of 40 and 100 ± 2°F were maintained from 6 to 12 hr prior to firing. Instrumentation connections were made, the rotating assembly was balanced at a rotational speed of 100 rpm (maximum vibration amplitude 3 mils), the nozzle closure was punctured, the S & A unit was armed, and a continuity check of all electrical systems was performed. Pre-fire, sea-level calibrations were completed, the test cell pressure was reduced to the desired pressure altitude condition, and spinning of the unit was started. After spinning had stabilized at 100 rpm, a complete set of altitude calibrations was taken.

The final operation prior to firing the motor was to adjust the firing circuit resistance and voltage to provide the desired 5-amp current to each of two igniter squibs (total of 10 amp). The entire instrumentation measuring-recording complex was activated, and the motor was fired while spinning (under power) at 100 rpm.

Spinning of the motor was continued for approximately 45 min after burnout, during which time post-fire calibrations were accomplished. The unit was decelerated slowly until rotation had stopped, and another set of calibrations was taken. The test cell pressure was then returned to ambient conditions, and the motor was inspected, photographed, and removed to the storage area. Post-fire inspections at the storage area consisted of measuring the throat and exit diameters of the nozzles, weighing the motors, and photographically recording the post-fire condition of the motors.

SECTION IV
RESULTS AND DISCUSSION

Eight JPL-SR-28-3 solid-propellant rocket motors were test fired under the combined effects of rotational spin at 100 rpm and an average

pressure altitude in excess of 100, 000 ft as the Qualification Test Phase of the Applications Technology Satellite Apogee Motor Program. The primary objective of the program was to determine motor performance during simulated inflight conditions. Secondary objectives were to measure motor case and nozzle structural integrity. The resulting data are presented in both tabular and graphical form.

Altitude ignition characteristics, ballistic performance, and structural integrity of the motors are discussed. Motor performance data are summarized in Table III. The average measured total impulse was corrected to vacuum conditions by adding to it the product of the cell pressure integral and the average of the pre- and post-fire nozzle exit area. The average vacuum correction was approximately 1.0 percent of the average measured total impulse. Specific impulse values are presented using both the manufacturer's stated propellant weight and the motor expended mass determined from AEDC pre- and post-fire motor weights. When more than one instrumentation channel was used to obtain values of a single parameter, the average value is discussed and used to calculate the data presented.

4.1 ALTITUDE IGNITION CHARACTERISTICS

The motors were successfully ignited at pressure altitudes in excess of 102, 000 ft. An analog trace of a typical ignition event is shown in Fig. 6. Ignition lag times, defined as the time interval from the time at which firing voltage is applied to the igniter circuit to the first indication of a rise in chamber pressure, ranged from 0.016 to 0.026 sec (average 0.22 sec).

4.2 BALLISTIC PERFORMANCE

Typical variations of thrust, chamber pressure, and cell pressure during the motor firings are shown in Fig. 7. Primary burn times (t_p) ranged from 43.0 to 45.20 sec. Action times (t_a) ranged from 41.90 to 43.6 sec. Vacuum corrected total impulse values (based on t_p) ranged from 213, 082 to 214, 100 lb_f-sec. Vacuum specific impulse, based on the manufacturer's stated propellant weight, ranged from 280.78 to 281.90 lb_f-sec/lb_m. Vacuum specific impulse, based on the expended mass and t_p, ranged from 277.57 to 278.37 lb_f-sec/lb_m. The average vacuum thrust coefficient, based on t_{bd} and the average of pre- and post-fire throat areas, ranged from 1.815 to 1.822 (average 1.818).

As during previous altitude tests (Ref. 2) distinct periods of residual burning occurred after the primary burn (Fig. 8). The duration of the

residual burning periods ranged from 6.0 to 23.0 sec after t_p during tailoff. Chamber pressure peaks varied from approximately 2.0 to 8.0 psia during the residual burning periods.

The impulse accumulated between t_p and the time the flow in the nozzle throat became subsonic (t_s) varied from 91 to 373 lb_f-sec (277 lb_f-sec average), as calculated using the expression

$$I = \bar{C}_f A_{e_{post\text{-}fire}} \int_{t_p}^{t_s} P_{ch} dt$$

Impulse accumulated from t_s until $P_{ch} = P_{cell}$ was considered negligible.

4.2.1 Influence of Pre-Fire Propellant Temperature

A comparison of the thrust curves for a typical firing of a motor conditioned at 100°F (firing 1) and one conditioned at 40°F (firing 8) is presented in Fig. 9. The typical cold motor thrust curve (t_p = 44.8 versus 43.1) is lower than the hot motor thrust throughout the firing, but the motor burns for a longer period. Average values of thrust, chamber pressure, and the primary burn times for each firing are presented in the table below:

Firing No.	Propellant Temperature, °F	Primary Burn Time, sec	Average Chamber Pressure over t_p, psia	Average Thrust over t_p, lb_f
1	100	43.0	207	4976
2	100	43.0	207	4976
3	100	43.4	206	4925
4	100	43.0	207	4977
Average for Firing Nos. 1 through 4		43.1	207	4964
5	40	44.8	198	4756
6	40	44.4	200	4809
7	40	44.7	199	4770
8	40	45.2	197	4729
Average for Firing Nos. 5 through 8		44.8	198	4766

The influence of pre-fire propellant grain temperature on specific impulse was evaluated during this test by using a statistical treatment of the I_{sp} data. The standard deviation (σ) of specific impulse (based on the manufacturer's stated propellant weight) was used to determine motor performance and measuring system repeatability. The σ values for the four motors in each temperature group are presented below.

Propellant Grain Temperature, °F	Number of Firings	Average Vacuum I_{sp}, lb_f-sec/lb_m	Average Deviation, σ, lb_f-sec/lb_m
40	4	280.94	0.173
100	4	281.59	0.224

4.3 STRUCTURAL INTEGRITY

Typical post-fire photographs of a motor case and nozzle are presented in Fig. 10. Circumferential delamination of the carbon cloth overwrap was evident along the internal surface of the nozzle extensions.

Pre- and post-fire inspection data revealed an average increase in nozzle throat areas of approximately 1.58 percent during the firings. The average decrease in nozzle exit area was approximately 0.76 percent during the firing (exhaust product deposition was not removed prior to the exit diameter measurements). There was no evidence of motor case deterioration. Structural integrity of motor and nozzle assemblies is considered adequate.

4.4 MOTOR TEMPERATURE VARIATIONS

Temperature measurements were obtained during firings 1, 3, 4, and 5. (Temperature measurements obtained during firings 3 and 4 were invalid because of unbonding of the thermocouples from the motor.) A comparison of typical temperature variations at three locations on the motor case for the two temperature conditioning modes is presented in Fig. 11. The pre-fire conditioning temperatures of 40°F (firings 5 through 8) and 100°F (firings 1 through 4) were maintained for 72 hr prior to the firings.

With the exception of the temperatures on the cylindrical section of the motor (thermocouple A8), the temperatures measured on the motor conditioned at 100°F were higher than the temperatures measured on the

40°F conditioned motor for the 300 sec presented (Figs. 11b and c). The temperatures on the cylindrical section of the motor cases conditioned at 40 and 100°F appeared to converge to approximately 600°F, 135 sec after ignition (Fig. 11a).

Figure 12 presents temperature variations for firing 5 (conditioned at 40°F). The maximum temperature recorded on the cylindrical section of the motor case was 715°F and occurred 130 sec after ignition. Maximum temperatures of 580, 602, and 1080°F were recorded for the forward dome, aft dome, and nozzle positions and occurred at 212, 108, and 73 sec after ignition, respectively.

SECTION V
SUMMARY OF RESULTS

Eight Jet Propulsion Laboratory JPL-SR-28-3 solid-propellant rocket motors were test fired under the combined effects of rotational spin (100 rpm) and near vacuum environment to determine motor performance and to evaluate motor and nozzle temperatures during and after the firing. The results are summarized as follows:

1. The time interval from time of increase in chamber pressure during ignition until the time of minimum chamber pressure at tailoff prior to residual burning (t_p), varied from 43.0 to 43.4 sec (43.1 sec average) for the four motors conditioned at 100°F and varied from 44.4 to 45.2 sec (44.8 sec average) for the four motors conditioned at 40°F.

2. Vacuum total impulse values based on t_p varied from 213,754 to 214,100 lb_f-sec (213,953 lb_f-sec average) for the four motors conditioned at 100°F and varied from 213,082 to 213,787 lb_f-sec (213,398 lb_f-sec average) for the four motors conditioned at 40°F. Vacuum specific impulse, based on the manufacturer's stated propellant weight and t_p, varied from 281.37 to 281.90 lb_f-sec/lb_m (281.59 lb_f-sec/lb_m average) for the four motors conditioned at 100°F and from 280.78 to 281.16 lb_f-sec/lb_m (280.94 lb_f-sec/lb_m average) for the four motors conditioned at 40°F.

3. The average vacuum thrust coefficient, based on t_{bd} and the average of pre- and post-fire throat areas, ranged from 1.815 to 1.822 (1.818 average).

4. Duration of the residual burning periods ranged from 6.0 to 23.0 sec after the primary burn during tailoff. Chamber pressure peaks varied from 2.0 to 8.0 psia with the calculated residual impulse accumulated ranging from 91 to 373 lb_f-sec (277 lb_f-sec average).

5. Erosion of the nozzle throat during the firings resulted in an average area increase of 1.58 percent. The nozzle exit areas decreased an average of approximately 0.76 percent during the firing.

6. The maximum motor case temperature of 715°F was measured on the cylindrical section during firing 5, 130 sec after ignition. The maximum nozzle temperature of 1080°F was measured 2 in. upstream of the nozzle exit, 73 sec after ignition.

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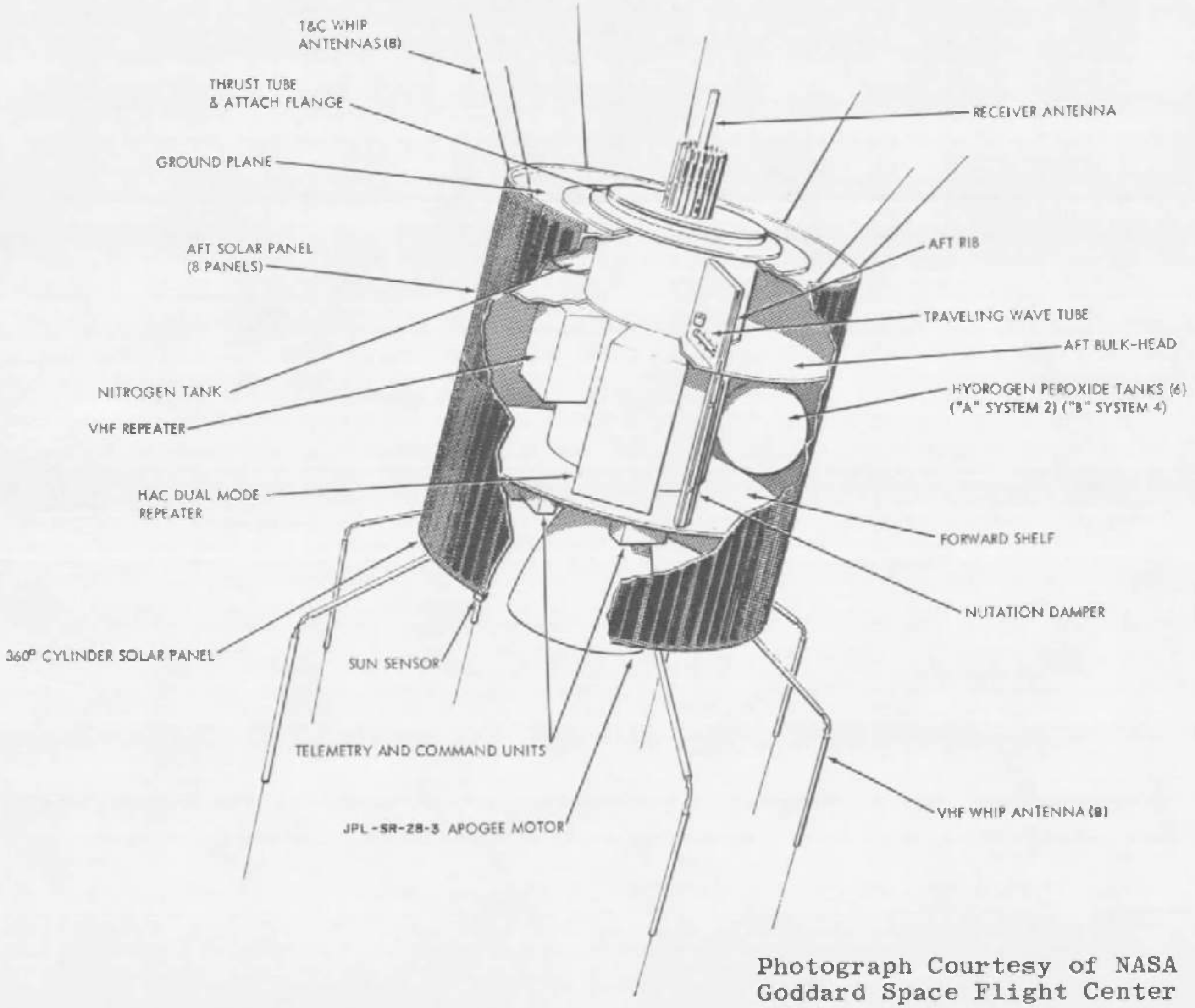


Photograph Courtesy of NASA
Goddard Space Flight Center

Fig. 1 Schematic of the Applications Technology Satellite

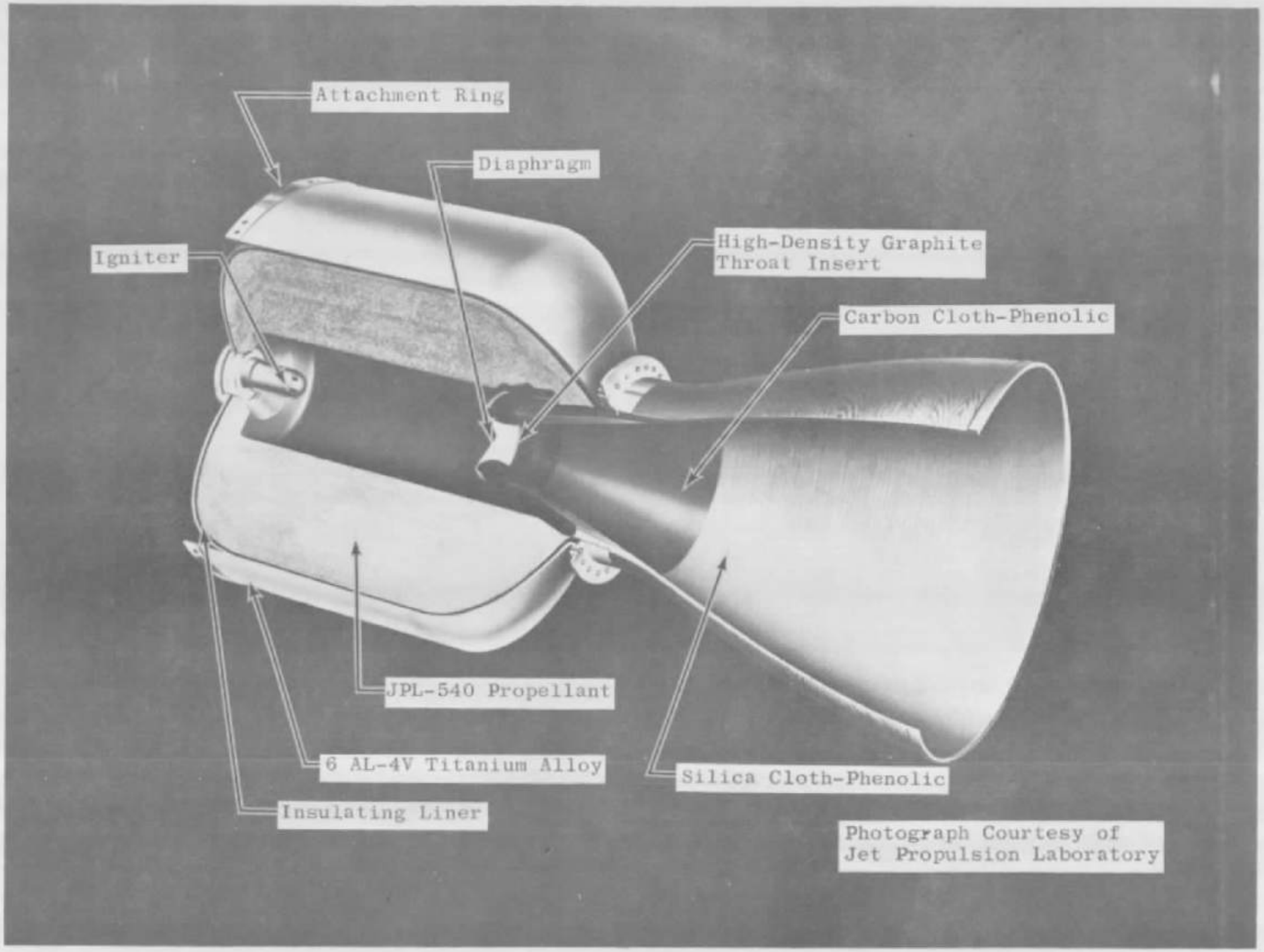


Fig. 2 JPL-SR-28-3 Solid-Propellant Rocket Motor Assembly

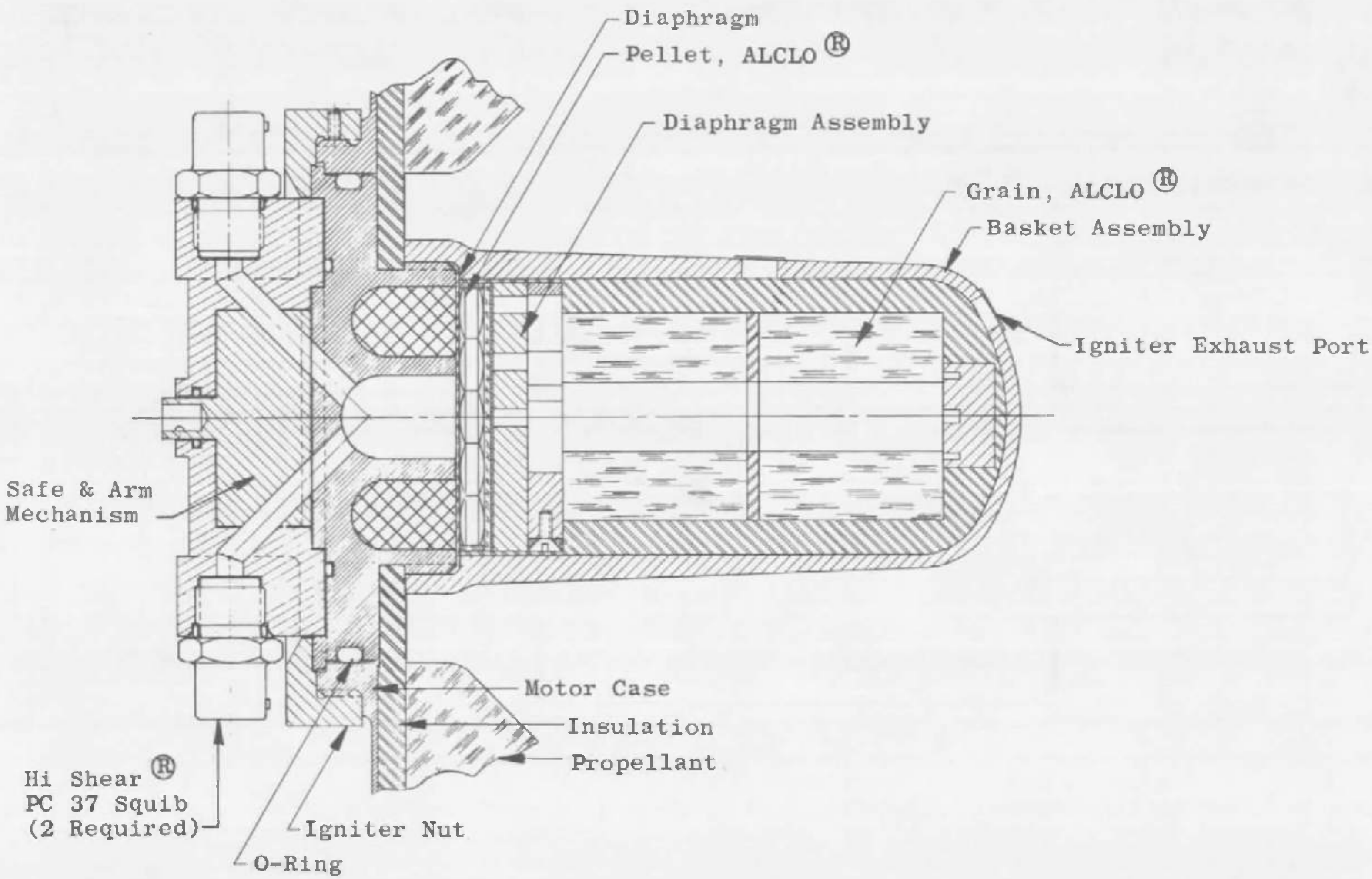
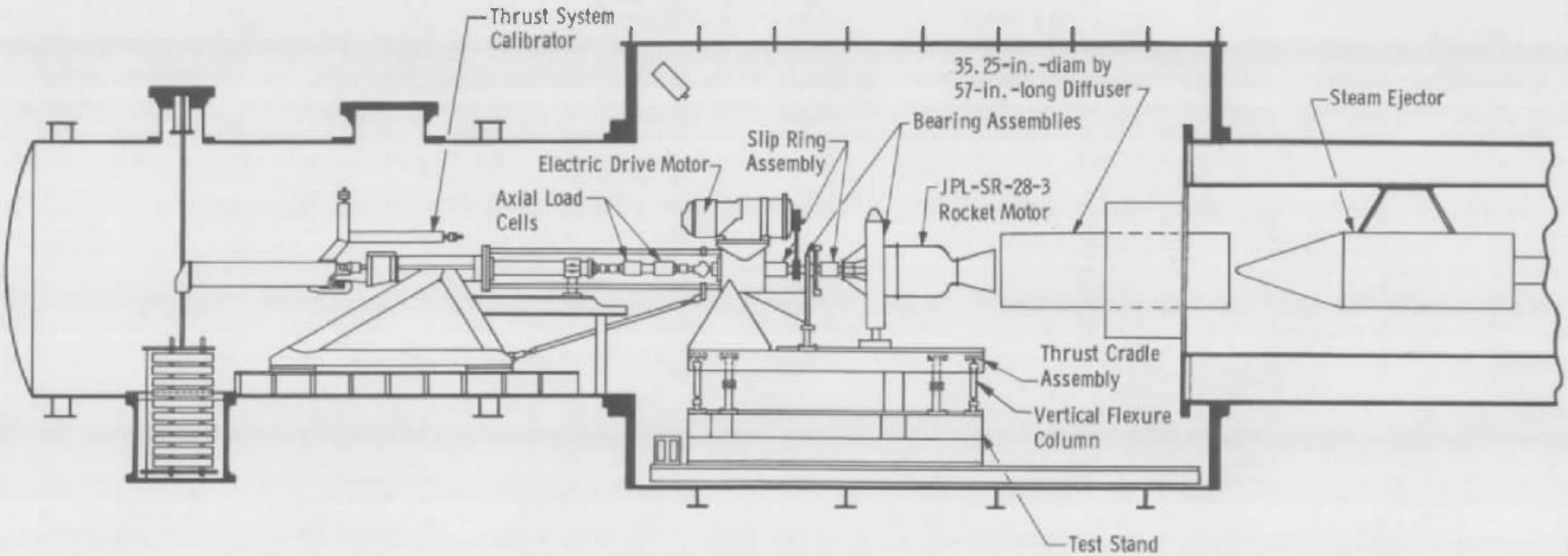
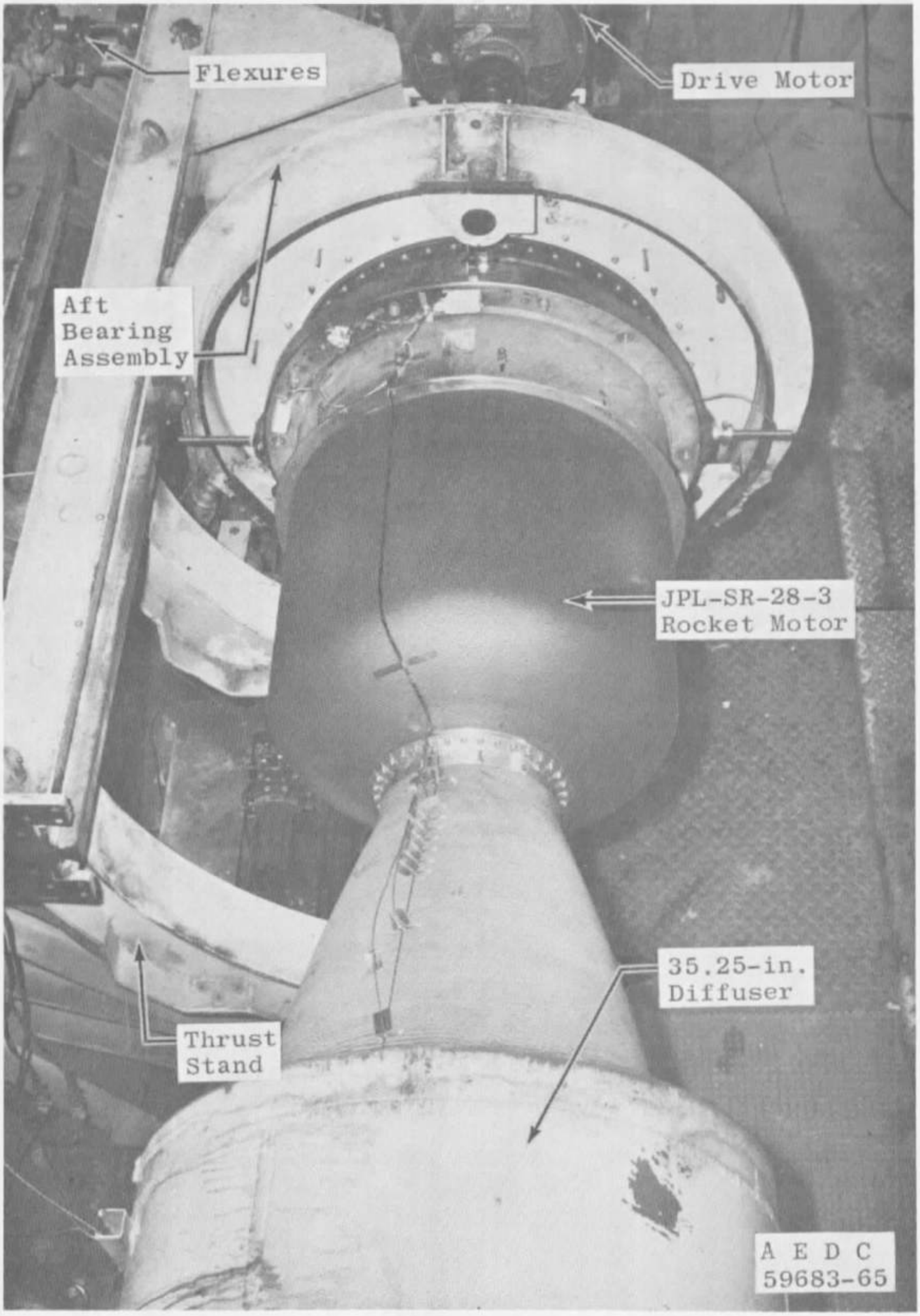


Fig. 3 Schematic of the Igniter and Safe-and-Arm Assembly



a. Schematic

Fig. 4 Installation of the JPL-SR-28-3 Rocket Motor in the T-3 Test Cell



b. Photograph
Fig. 4 Concluded

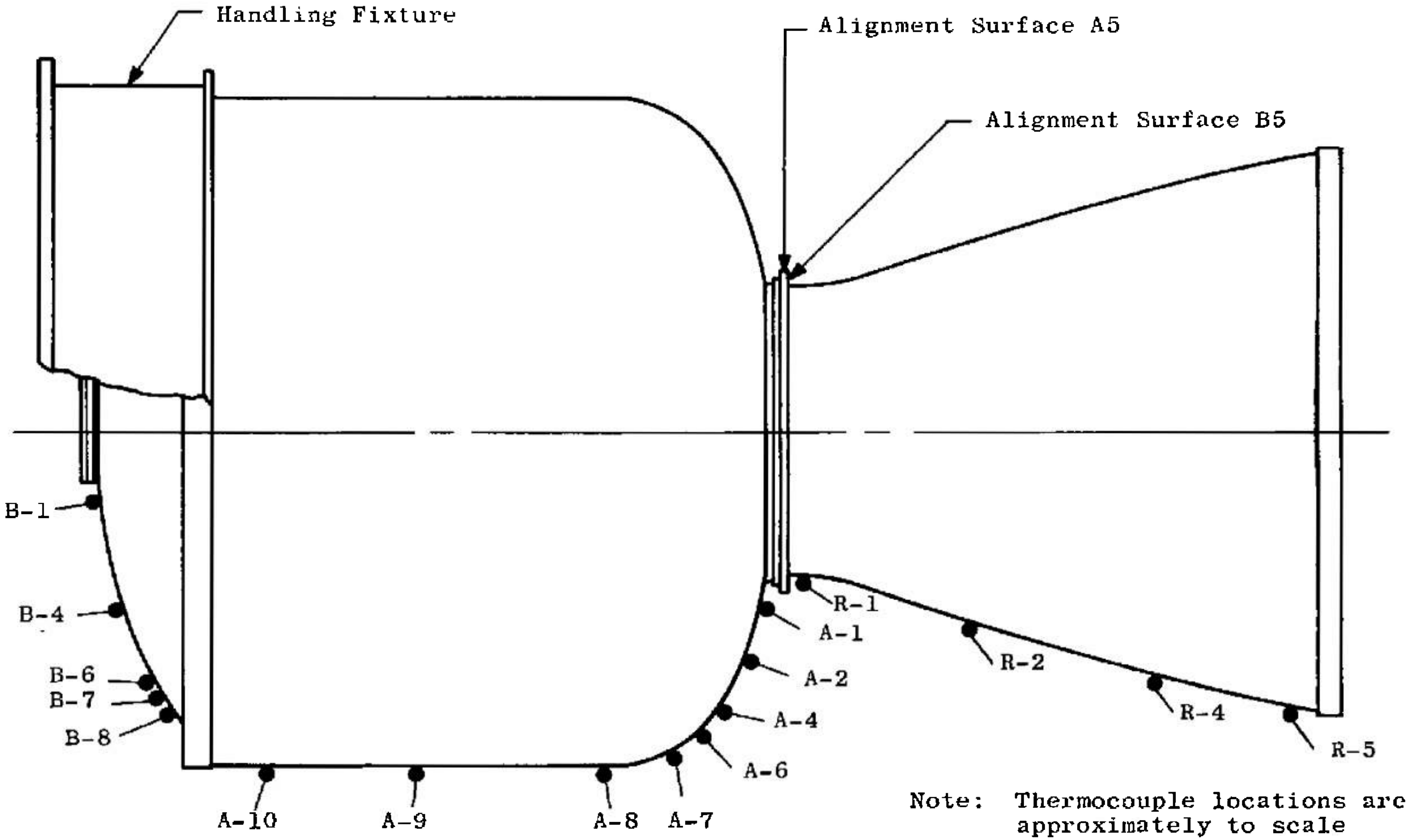


Fig. 5 Thermocouple and Alignment Surface Locations on the Motor Assembly

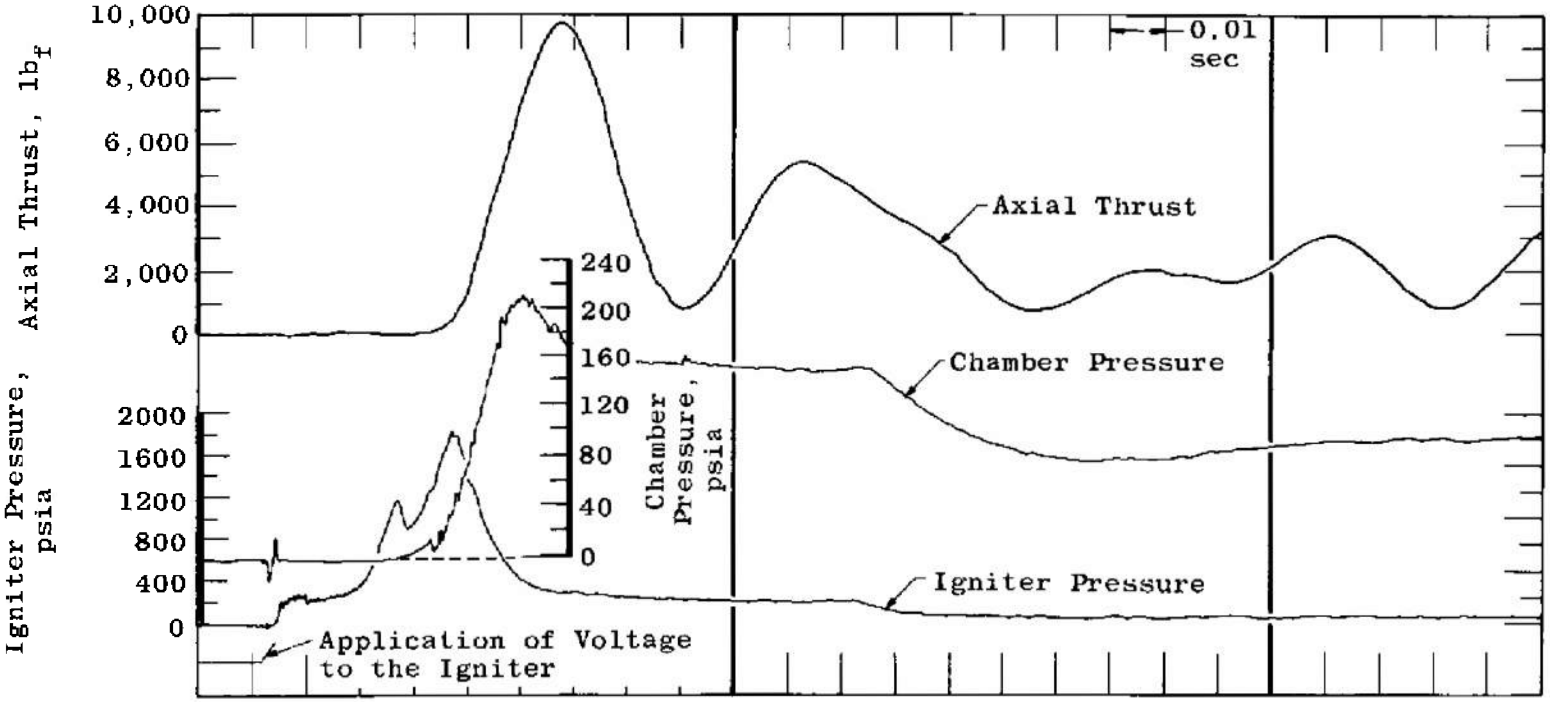


Fig. 6 Analog Trace of a Typical JPL ATS Apogee Motor Ignition Event

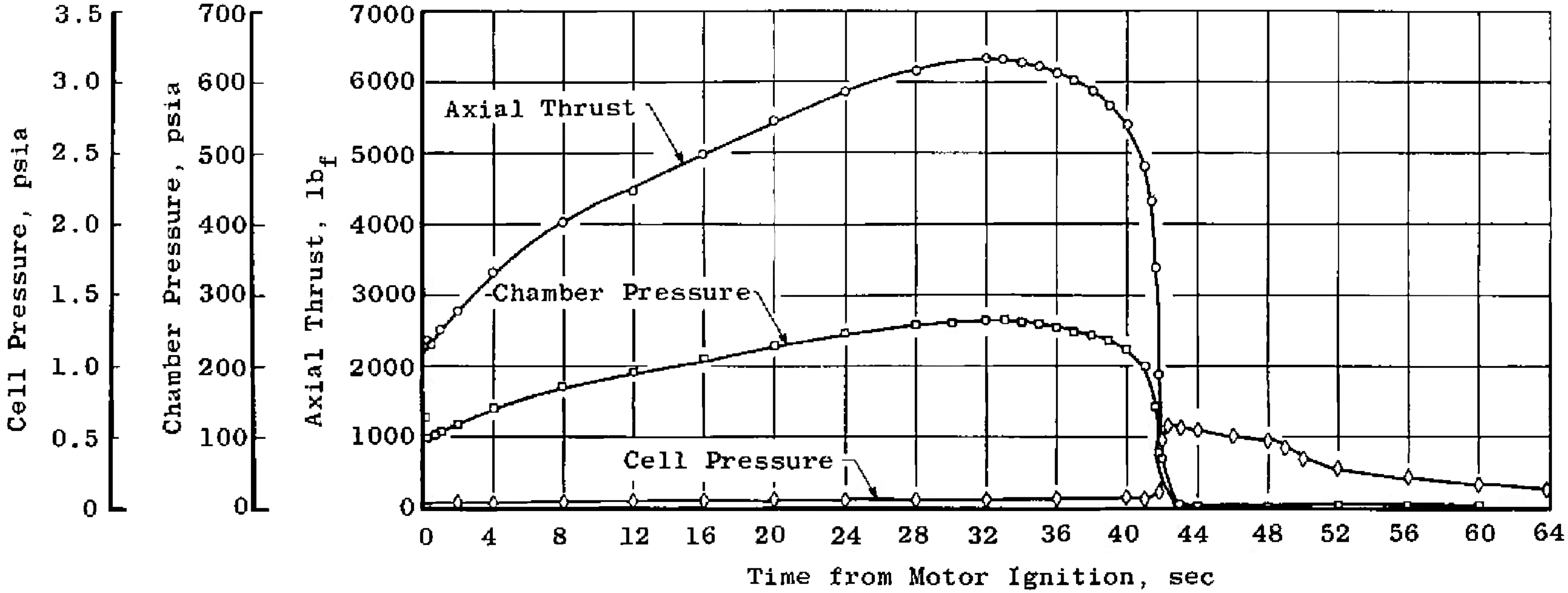


Fig. 7 Typical Motor Performance Parameters as a Function of Burn Time

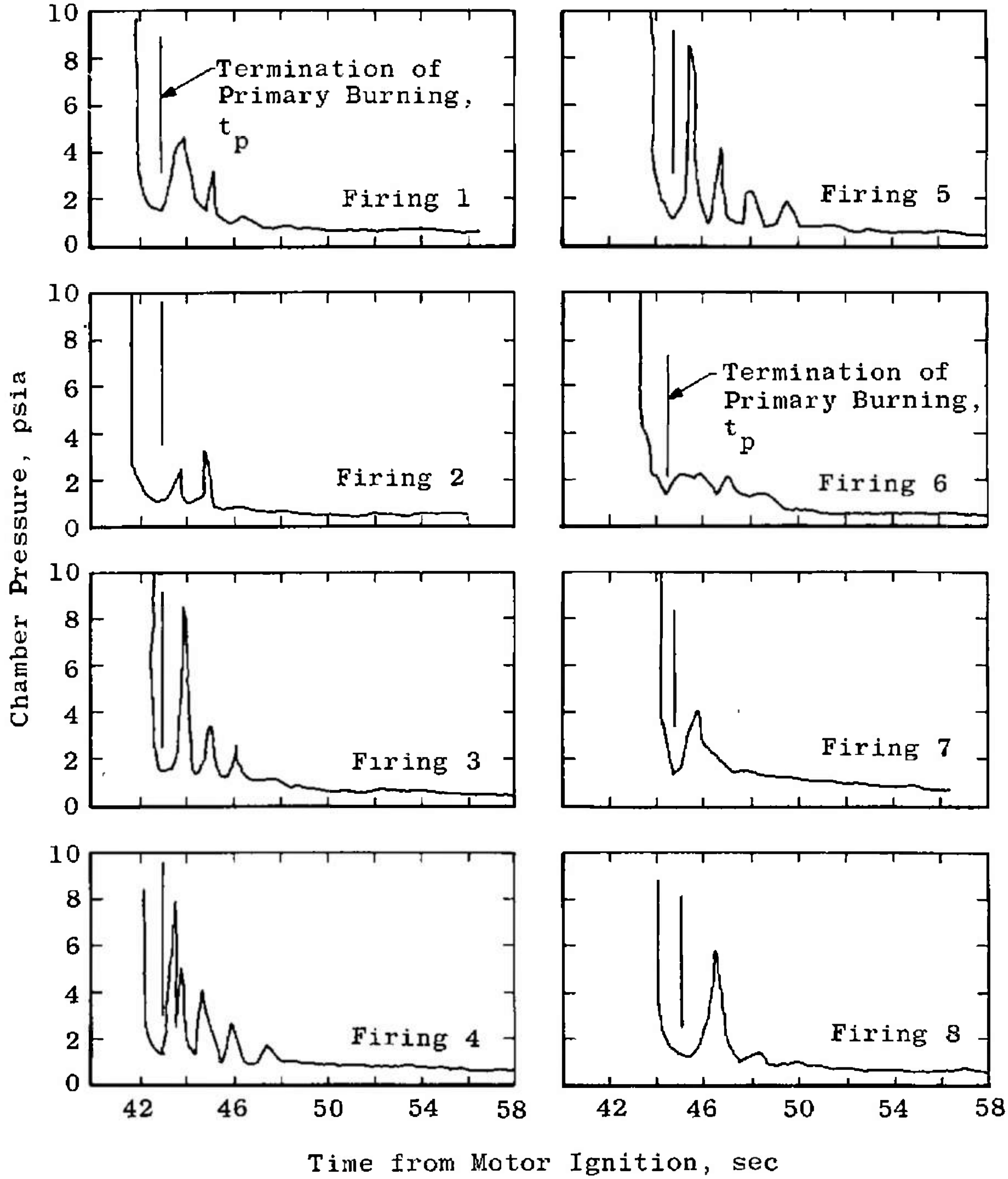


Fig. 8 Chamber Pressure-Time History during Residual Burning

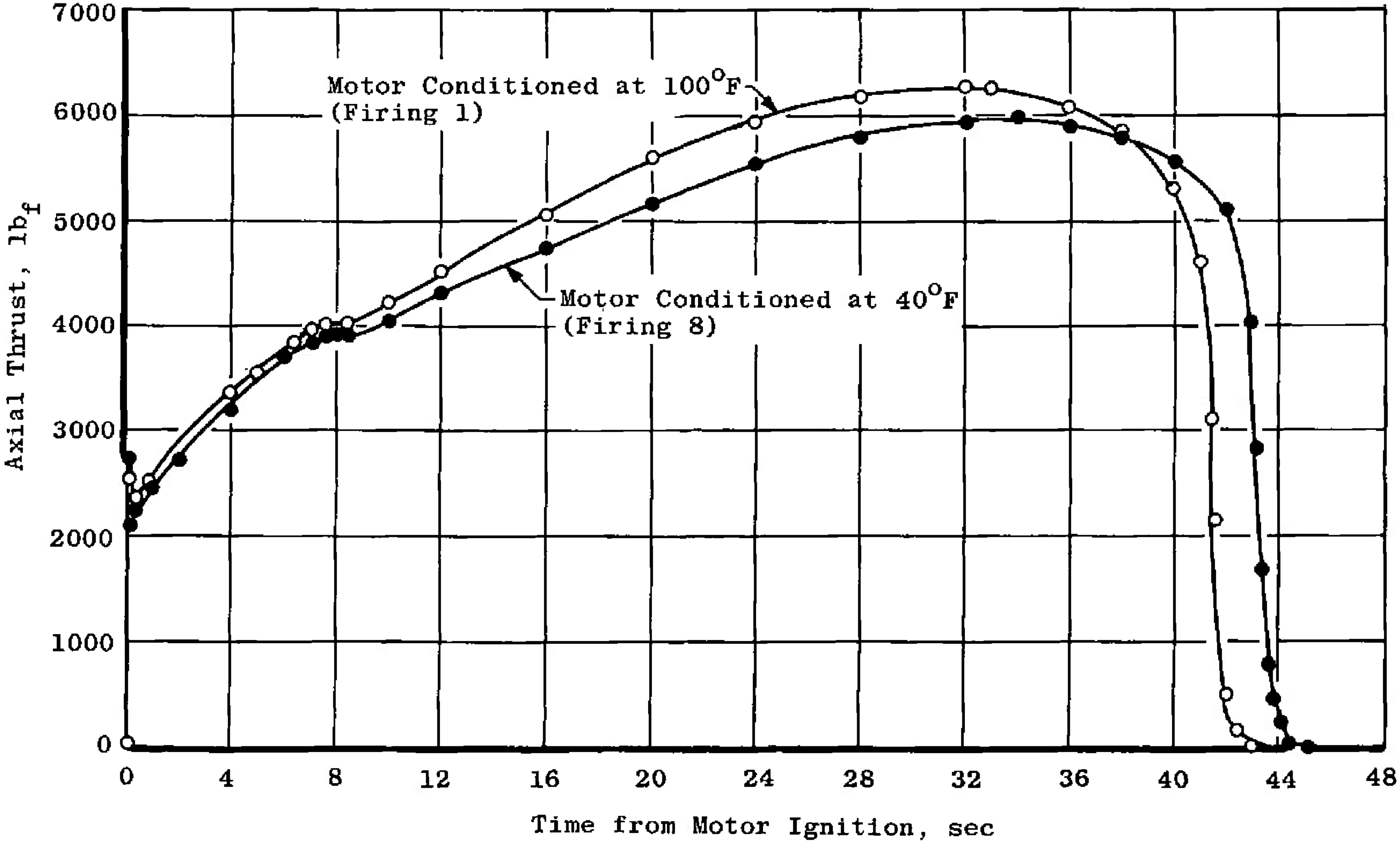
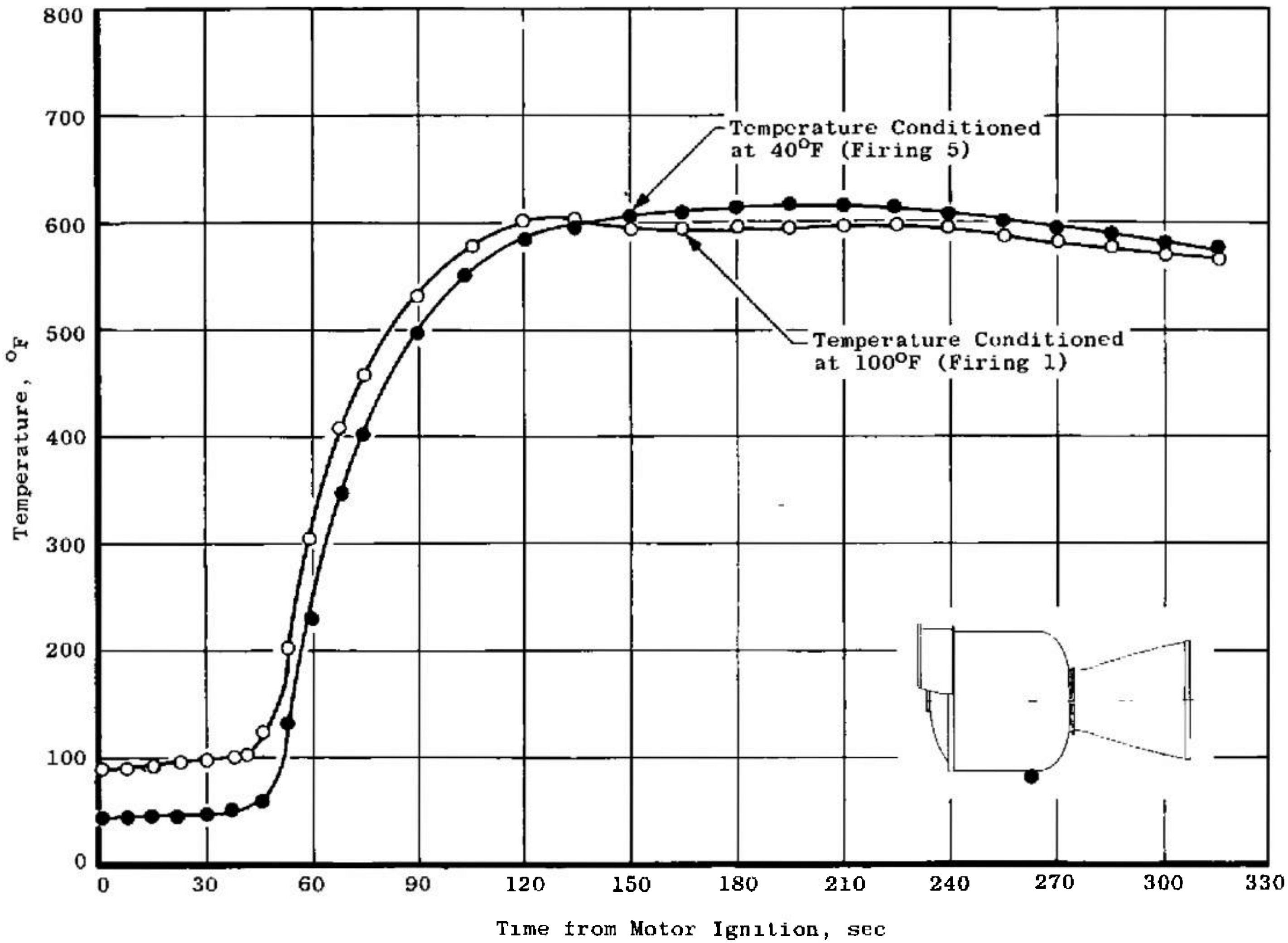


Fig. 9 Influence of Pre-Fire Propellant Temperature on Motor Thrust

a. Motor Assembly

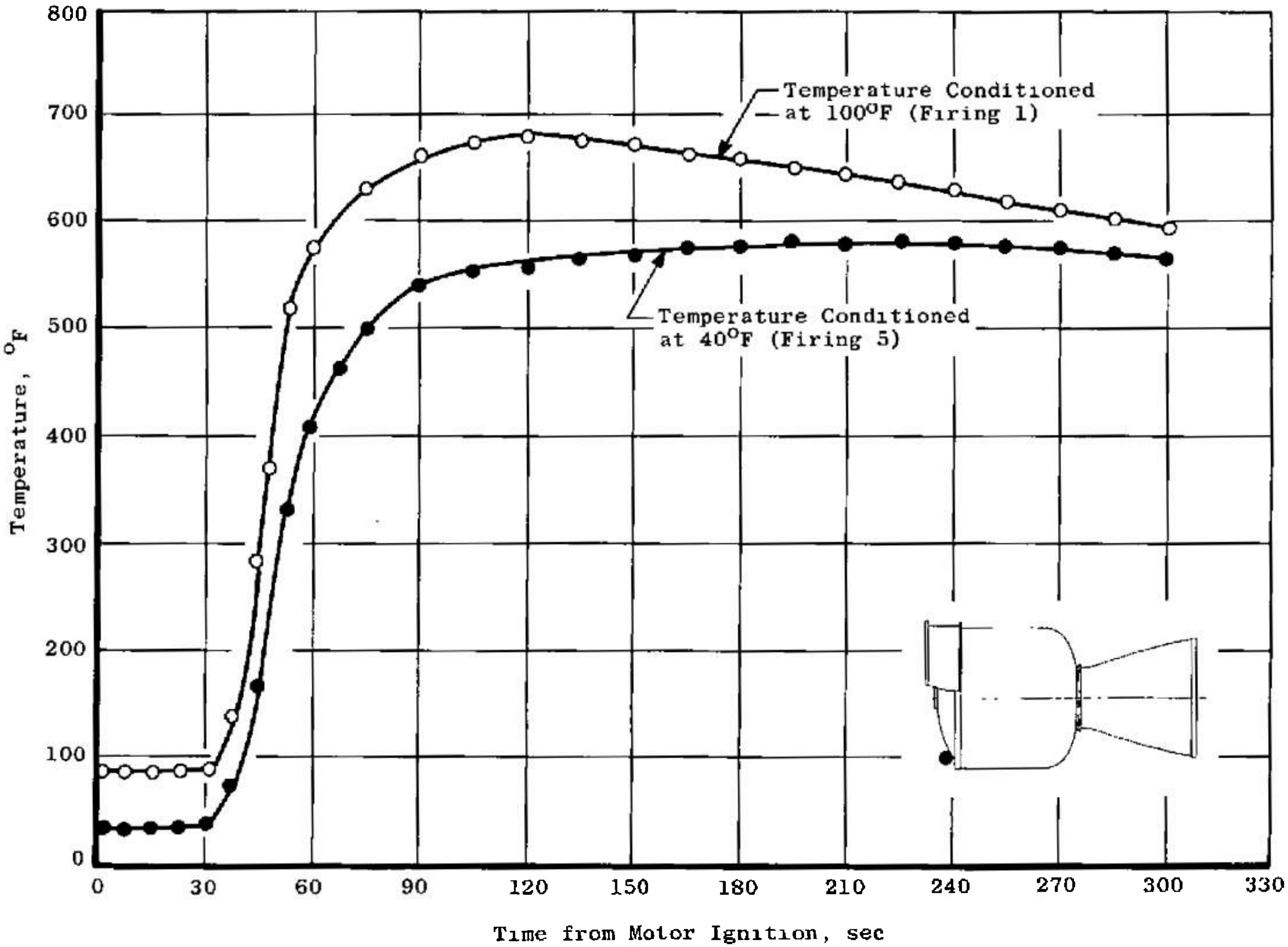
Fig. 10 Typical Post-Fire Photograph of the Motor

b. Nozzle
Fig. 10 Concluded



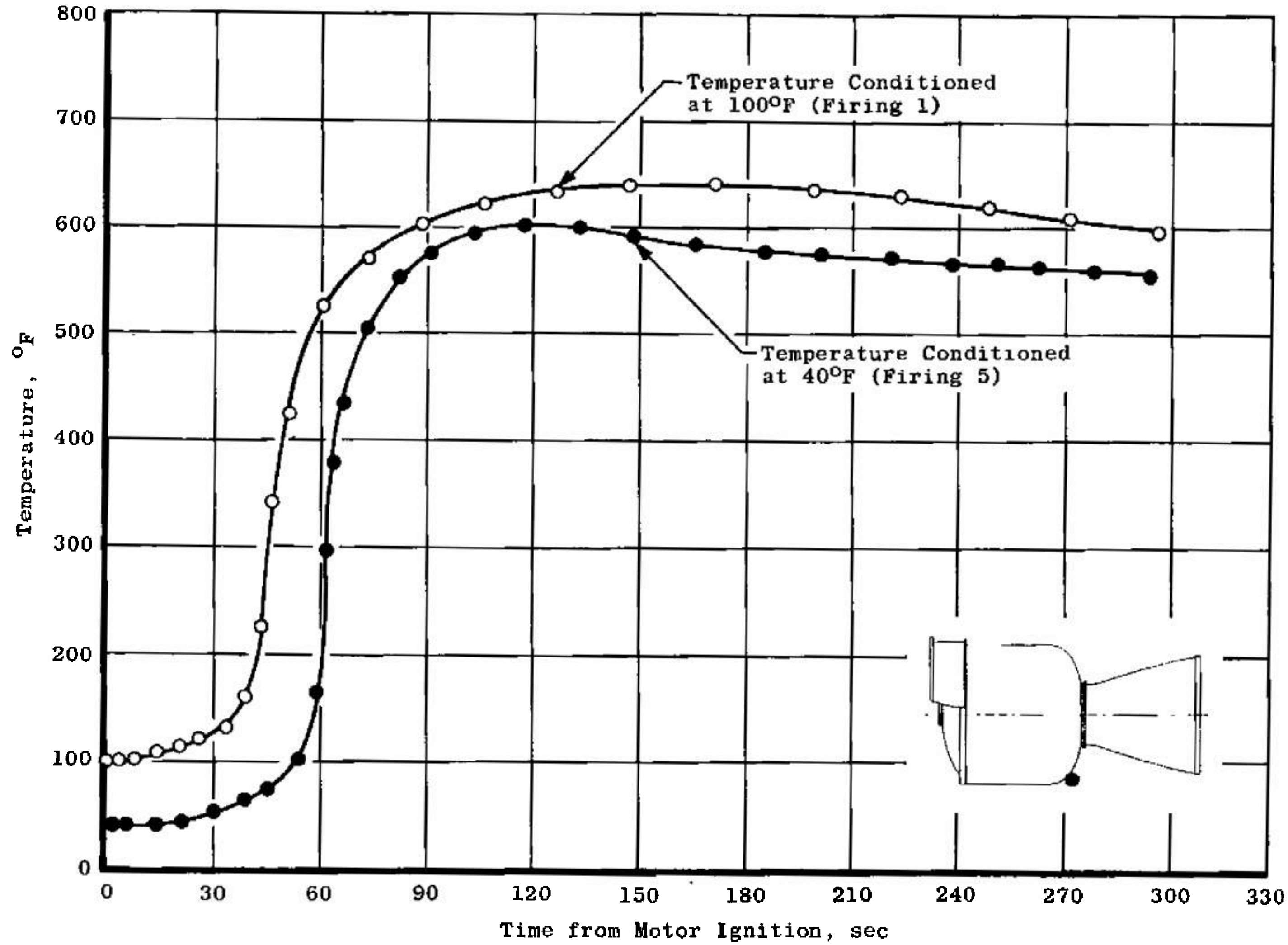
a. Cylindrical Section (A 8)

Fig. 11 Temperature-Time History Comparison of Typical 40 and 100°F Conditioned Motors



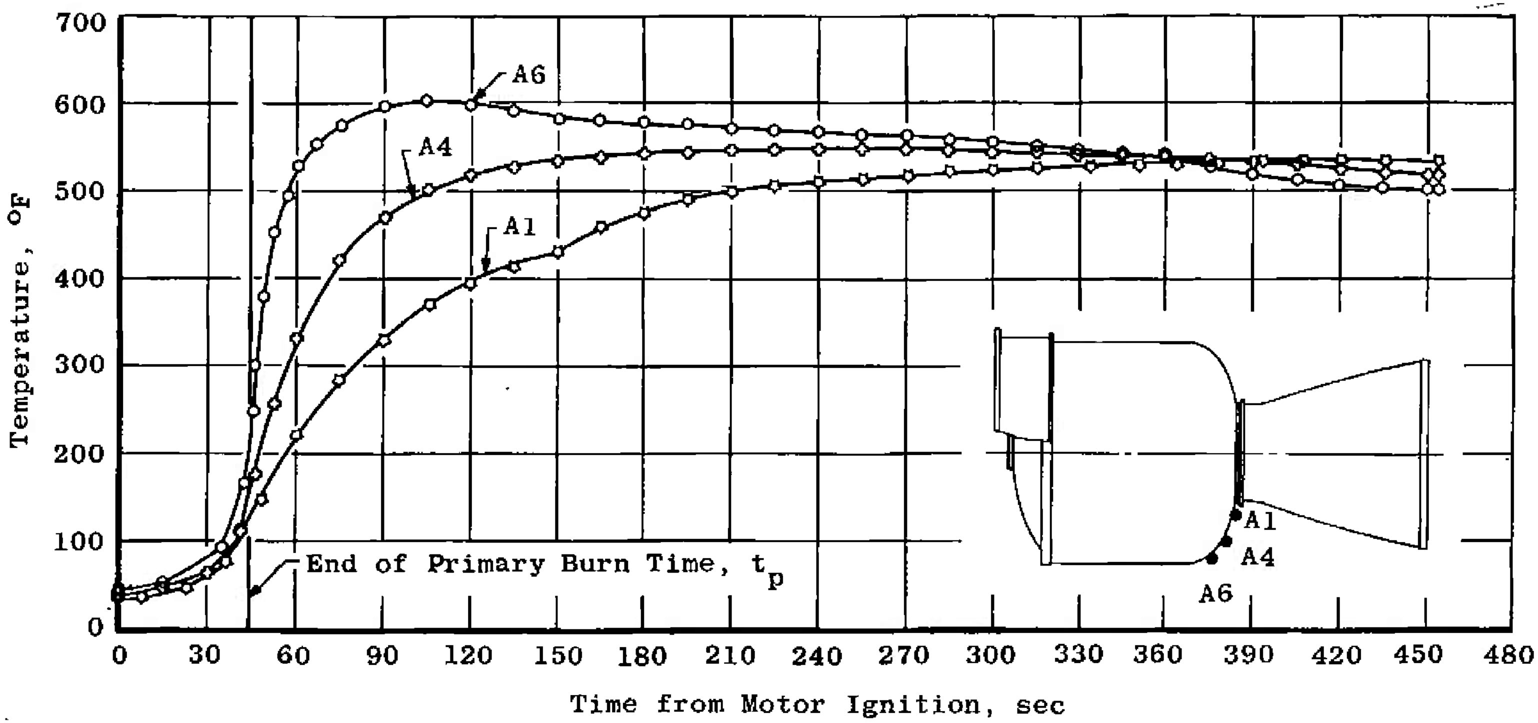
b. Forward Dome (B8)

Fig. 11 Continued



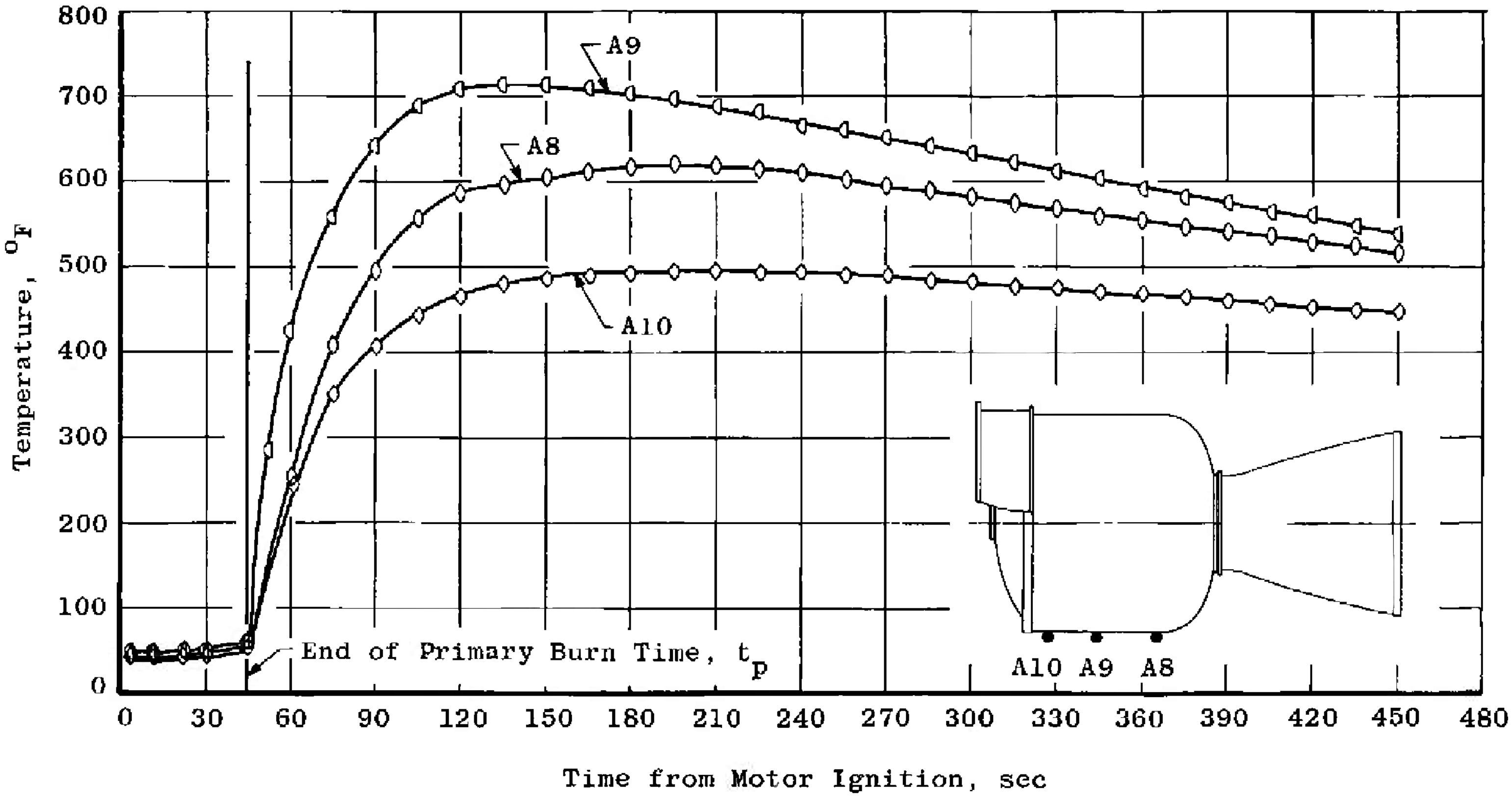
c. Aft Dome (A6)

Fig. 11 Concluded



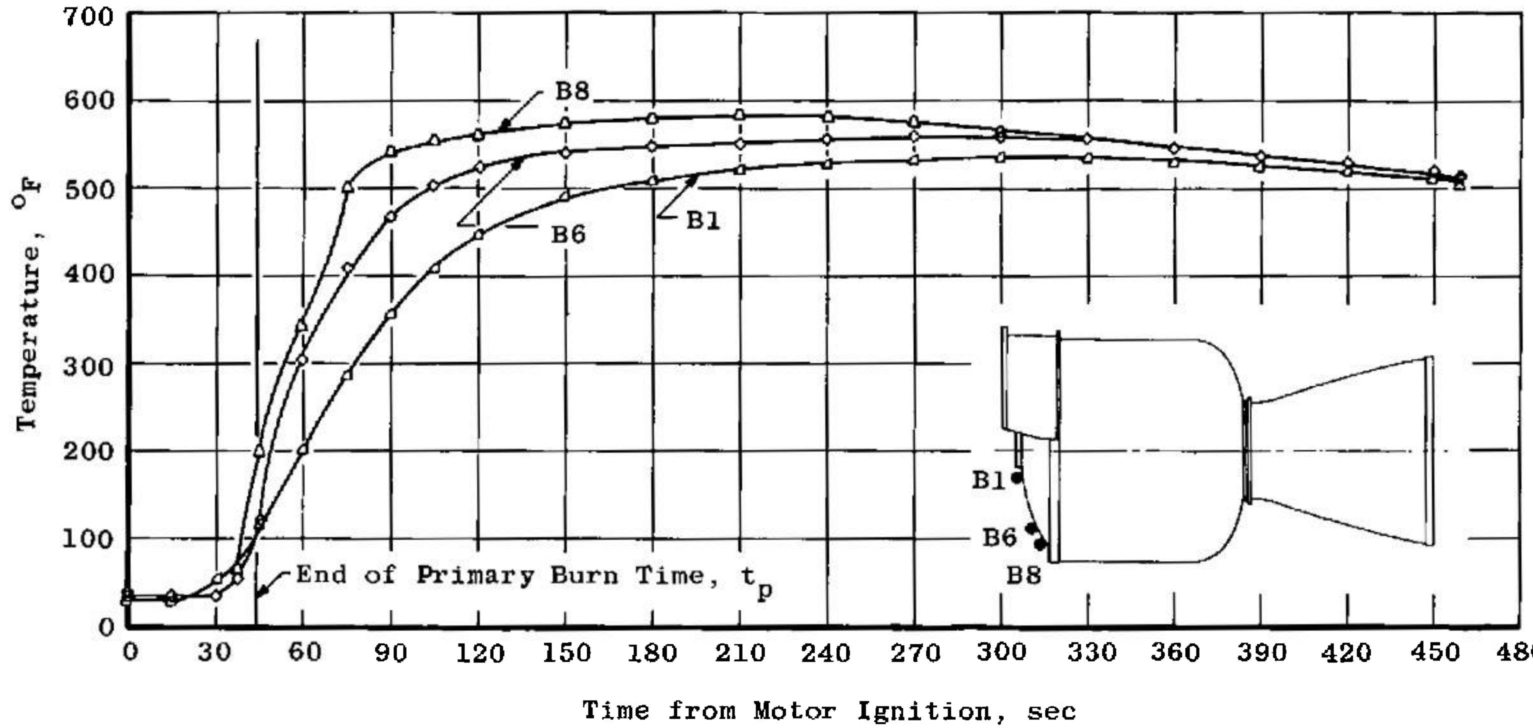
a. Aft Dome

Fig. 12 Temperature-Time Histories as a Function of Position for a Motor Conditioned at 40°F



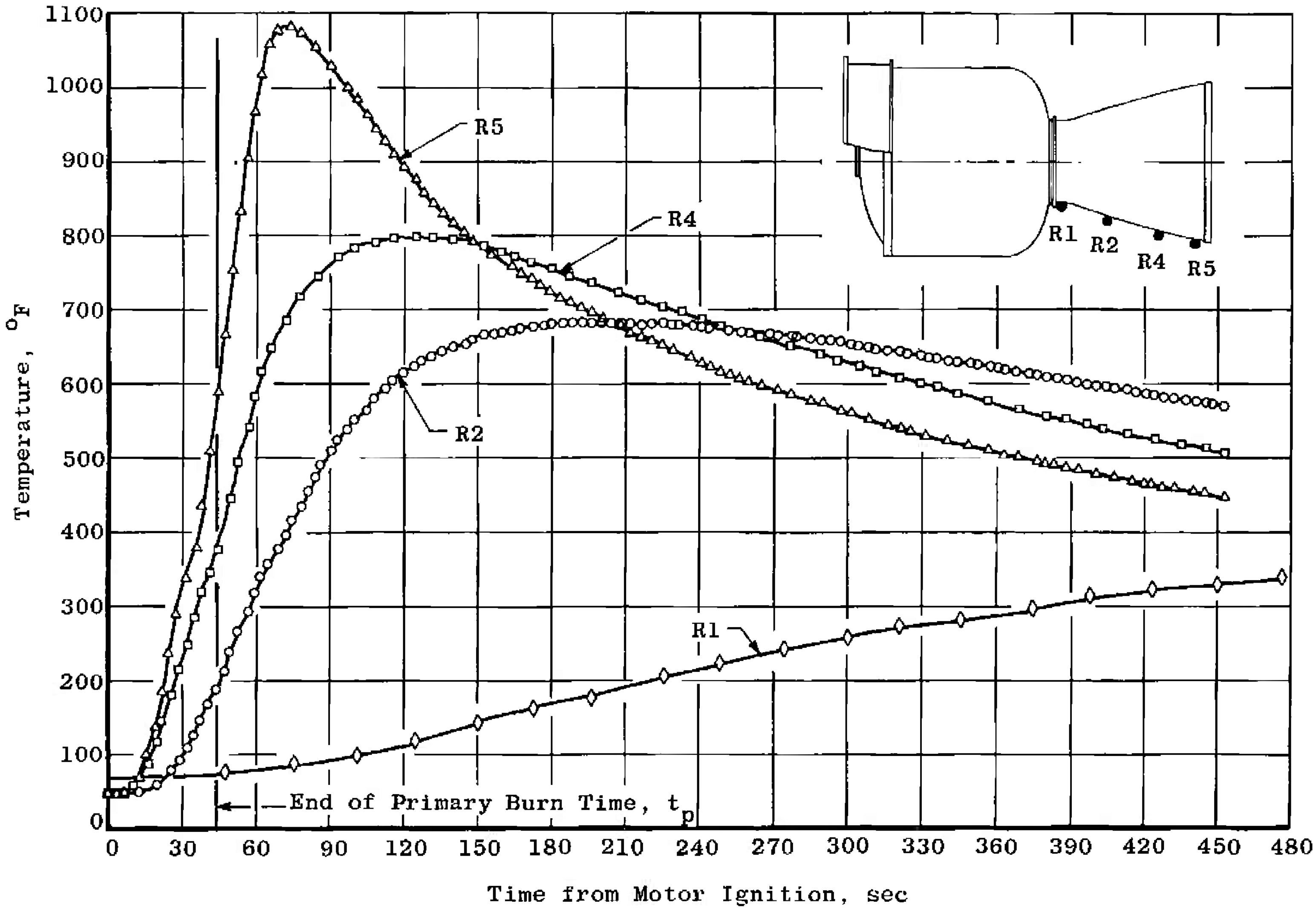
b. Cylindrical Section

Fig. 12 Continued



c. Forward Dome

Fig. 12 Continued



d. Nozzle

Fig. 12 Concluded

TABLE I
SUMMARY OF MOTOR PHYSICAL DIMENSIONS

Motor Serial Number	Q-8T	Q-6T	Q-2T	Q-4T	Q-5T	Q-7T	Q-1T	Q-3T
Firing Number	1	2	3	4	5	6	7	8
Test Date	7/29	8/3	8/5	8/8	8/15	8/18	8/19	8/23
Manufacturer's Propellant Weight, lb_m	760.0	759.5	759.7	760.0	758.9	759.4	759.2	760.8
Expended Mass (AEDC) (Includes Igniter Weight), lb_m	769.03	769.11	768.88	769.15	767.44	768.72	768.12	769.85
Nozzle Throat Area, $in.^2$								
Pre-Fire	13.090	13.093	13.090	13.113	13.097	13.093	13.093	13.090
Post-Fire[1]	13.314	13.365	13.303	13.311	13.280	13.280	13.282	13.282
Percent Change from Pre-Fire	+1.71	+2.08	+1.60	+1.51	+1.40	+1.43	+1.44	+1.47
Average	13.2020	13.2290	13.1965	13.2118	13.1882	13.1865	13.1877	13.1860
Nozzle Exit Area, $in.^2$								
Pre-Fire	458.012	457.760	457.317	458.012	457.715	457.741	457.816	457.614
Post-Fire[1]	455.979	455.663	453.522	453.019	454.057	453.459	452.736	455.758
Percent Change from Pre-Fire	-0.44	-0.46	-0.83	-1.09	-0.80	-0.94	-1.11	-0.41
Average	456.996	456.7110	455.4510	455.5154	455.8859	455.600	455.2760	456.6859
Nozzle Area Ratio								
Pre-Fire	34.99	34.96	34.94	34.93	34.95	34.96	34.97	34.96
Post-Fire	34.25	34.09	34.09	34.03	34.19	34.15	34.09	34.31
Average	34.62	34.52	34.51	34.48	34.57	34.55	34.52	34.63

[1]Exhaust product deposition not removed prior to the measurements.

TABLE II
INSTRUMENTATION DESCRIPTION

Parameter	Estimated System Accuracy		Measuring Device	Range of Measuring Device	Recording Device	Method of System Calibration
	Steady-State at Operating Level	Integral, percent				
Axial Force, lb_f	±0.31 percent	- -	Bonded Strain-Gage-Type Load Cells (2 used)	0 to 10,000 lb_f	Millivolt-to-Frequency or Digital Converter onto Magnetic Tape	Deadweight
Total Impulse, lb_f-sec	---	±0.30				
Motor Chamber Pressure, psia	±0.42 percent	---	Bonded Strain-Gage-Type Transducers (2 used)	0 to 300 psia		Electrical
Chamber Pressure Integral, psia-sec	---	±0.41				
Low-Range Chamber Pressure, psia	±2.0 percent	---		0 to 15 psia		
Test Cell Pressure, psia	±1.68 percent	---	Unbonded Strain-Gage-Type Transducers (2 used)	0 to 1.0 psia		
Test Cell Pressure Integral, psia-sec	---	±1.67				
Time Interval, msec	±2 msec	---	Synchronous Timing Line Generator	---	Photographically Recording Galvanometer-Type Oscillograph	Compare with 60 cps
Temperature, °F	±10°F	---	Chromel®-Alumel® Thermocouples	0 to 1000°F	Digital Millivoltmeter onto Magnetic Tape	Known Millivolt Source and NBS Temperature Tables
Weight, lb_m	±0.03 lb_m	---	Beam Balance Scales	0 to 3000 lb_m	Visual Readout	Periodic Deadweight Calibration

TABLE III
ATS APOGEE MOTOR PERFORMANCE SUMMARY

Firing Number	1	2	3	4	5	6	7	8
Motor Serial Number	Q-8T	Q-6T	Q-2T	Q-4T	Q-5T	Q-7T	Q-1T	Q-3T
Conditioning Temperature, °F	100	100	100	100	40	40	40	40
Test Date	7/29/66	8/3/66	8/5/66	8/8/66	8/15/66	8/18/66	8/19/66	8/23/66
Average Spin Rate, rpm	101.9	101.4	101.2	101.3	101.6	102.2	101.7	100.9
Ignition Altitude, ft	124,000	128,000	125,000	108,000	114,000	102,000	104,000	125,000
Ignition Lag Time (t_ℓ), sec	0.022	0.019	0.024	0.016	0.021	0.018	0.020	0.026
Nozzle Flow Breakdown Time (t_{bd}), sec	41.70	11.60	41.90	41.60	42.90	42.60	42.80	43.20
Action Time (t_a), sec	42.00	41.90	42.40	42.00	43.30	43.00	43.30	43.60
Primary Burn Time (t_p), sec	43.00	13.00	43.40	43.00	44.80	44.40	44.70	45.20
Time Nozzle Flow Goes Subsonic (t_s), sec	48.9	46.3	65.9	59.[illegible]	67.8	52.3	02.70	62.2
Measured Total Impulse (Average of Four Channels, Based on t_{bd}), lb_f-sec	211,413	211,710	210,990	211,155	210,098	210,328	210,005	210,950
Maximum Deviation from Average, percent	0.001	0.005	0.009	0.002	0.01	0.006	0.02	0.005
Chamber Pressure Integral (Average of Two Channels, Based on t_{bd}), psia-sec	8890.7	8882.5	8886.7	8894.4	8857.4	8866.7	8837.8	8863.4
Maximum Deviation from Average, percent	0.04	0.04	0.04	0.05	0.007	0.03	0.02	0.02
Cell Pressure Integral (Average of Three Channels, Based on t_{bd}), psia-sec	4.5511	4.0789	4.2045	4.6686	4.7548	5.2230	4.9107	4.4278
Maximum Deviation from Average, percent	0.46	0.36	0.38	0.33	0.89	0.72	0.50	0.38
Average Simulated Altitude (Based on t_{bd}), ft	109,000	111,000	110,000	108,000	108,000	106,000	108,000	110,000
Vacuum Total Impulse (Based on t_p), lb_f-sec	213,851	214,100	213,754	214,009	213,082	213,514	213,209	213,787
Chamber Pressure Integral (from t_{bd} to t_p), psia-sec	18.90	21.95	39.1	30.15	33.85	33.45	39.95	33.65
Average Vacuum Thrust Coefficient (Based on 1 sec of Data 1 sec before t_{bd} and Post-Fire Throat Area), $\overline{C}_F$	1.821	1.816	1.821	1.813	1.815	1.816	1.824	1.824
Vacuum Specific Impulse, lb_f-sec/lb_m								
Based on Manufacturer's Stated Propellant Weight	281.51	281.00	281.37	281.59	280.78	281.16	280.88	281.00
Based on Expended Mass	278.21	278.37	278.01	278.24	277.65	277.75	277.57	277.70
Chamber Pressure Integral between t_p and t_s, psia-sec	8.3	3.8	15.01	14.5	14.2	6.7	15.4	13.6
Calculated Vacuum Impulse between t_p and t_s, lb_f-sec	201	91	364	350	342	162	373	329
Average Vacuum Thrust Coefficient (Based on t_{bd} and Average Pre- and Post-Fire Throat Areas), $\overline{C}_F$	1.819	1.818	1.815	1.815	1.817	1.819	1.821	1.822

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RESULTS OF THE QUALIFICATION TEST OF EIGHT JPL-SR-28-3 ROCKET MOTORS AT SIMULATED ALTITUDE

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13. ABSTRACT

Eight Jet Propulsion Laboratory JPL-SR-28-3 solid-propellant rocket motors were test fired under the combined effects of rotational spin at 100 rpm, temperature conditioning at 100°F (4 motors) and 40°F (4 motors), and an average pressure altitude in excess of 100,000 ft, as the Qualification Test Phase of the Applications Technology Satellite Apogee Motor Program. The primary objective of the program was to determine motor performance during simulated flight conditions. Secondary objectives were to measure motor case and nozzle temperatures for 300 sec after ignition and to evaluate the motor case and nozzle structural integrity. Motor performance is presented and compared with data from earlier AEDC test firings of the same type of motor.

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14 KEY WORDS	LINK A		LINK B		LINK C	
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